Physics 221, Fall 2008

Quiz 2, Form: $\boxed{\text{A}}$

Name: Key

Date:

$G = 6.7 \times 10^{-11}\ \text{Nm}^2/\text{kg}^2$

$\frac{1}{4\pi\varepsilon_o} = 9 \times 10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}$

Section 1. Multiple Choice

1. At Earth's surface, the magnitude of Earth's gravitational field is 9.8 N/kg. How far *from the center of Earth* is the gravitational field one-fourth this value (2.45 N/kg)?

   (a) $|\vec{r}| = \sqrt{2}R_{Earth}$

   (b) $|\vec{r}| = (1/2)R_{Earth}$

   (c) $|\vec{r}| = R_{Earth}$

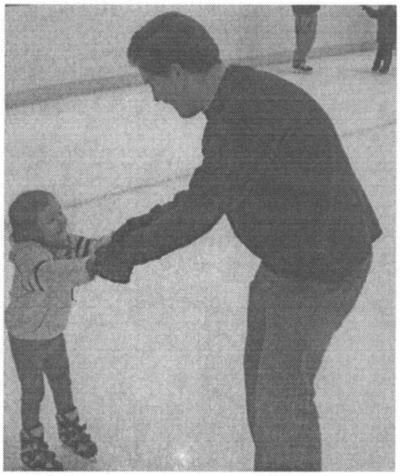
   [✓ (d)] $|\vec{r}| = 2R_{Earth}$

   (e) $|\vec{r}| = 4R_{Earth}$

$$F_{grav} \propto \frac{1}{|\vec{r}|^2}$$

$$\frac{1}{|2\vec{r}|^2} = \frac{1}{4|\vec{r}|^2} \overset{\text{gives}}{\Rightarrow} \frac{1}{4}\vec{F}_{grav}$$

Questions 2–5: A father and daughter are standing on ice (with ice skates on) as shown below. Because of low friction, the net external force on the system of father and daughter is zero.



Suppose that each person pushes the other person's hands so that they move apart. The father exerts an average force of $< -50, 0, 0 >$ N on his daughter while they are pushing each other. The average force by the daughter on her dad during the same time interval is

2. (a) zero

   (b) more than 50 N, in the $+x$ direction.

   (c) less than 50 N, in the $+x$ direction.

   [✓ (d)] 50 N, in the $+x$ direction.

   (e) 50 N, in the $-x$ direction.

$\overleftarrow{\vec{F}_{\text{by dad on girl}}}$ $\quad$ $\overrightarrow{\vec{F}_{\text{by girl on dad}}}$

Newton's Third Law

3. During the time interval Δt that they are pushing each other apart, which person will have a greater $|\Delta\vec{p}|$?

   (a) the dad

   (b) the daughter

   [✓ (c)] neither, because they will have the same $|\Delta\vec{p}|$.

$$|\vec{F}_{net}|_{dad} = |\vec{F}_{net}|_{girl}$$

$$\frac{|\Delta\vec{p}_{dad}|}{\Delta t} = \frac{|\Delta\vec{p}_{girl}|}{\Delta t}$$

4. During the time interval Δt that they are pushing each other apart, which person will have a greater $|\Delta\vec{v}|$?

$|\Delta\vec{p}| = m|\Delta\vec{v}|$ is same

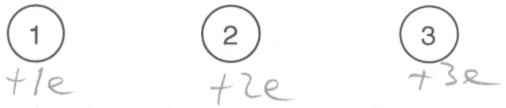
small m, big $|\Delta\vec{v}|$

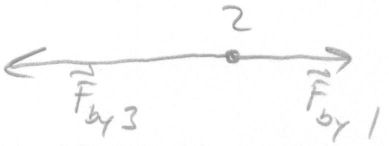
   (a) the dad
   [✓ (b)] the daughter
   (c) neither, because they will have the same $|\Delta\vec{v}|$.

5. During the time interval Δt that they are pushing each other apart, which person will have a greater displacement, $|\Delta\vec{r}|$?

   (a) the dad
   [✓ (b)] the daughter
   (c) neither, because they will have the same $|\Delta\vec{r}|$.

Questions 6–7: Three charged particles are shown below.





Particle 1 has a charge $q_1 = +1e$, Particle 2 has a charge $q_2 = +2e$, and Particle 3 has a charge $q_3 = +3e$ where e is the magnitude of the charge of an electron (or proton), $e = 1.6 \times 10^{-19}$ C.

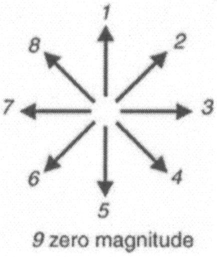
6. Which particle exerts a larger magnitude force on Particle 2?

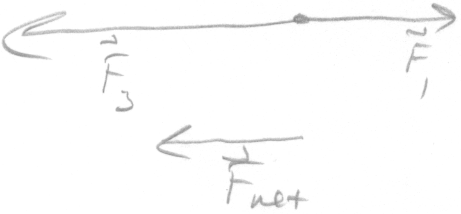
$$|\vec{F}_{coul}| = (9\times10^9)\frac{q_1 q_2}{|\vec{r}|^2}$$

   (a) Particle 1
   [✓ (b)] Particle 3
   (c) Neither, because they exert equal magnitude forces on Particle 2.

7. Which arrow below points in the direction of the net force on Particle 2?

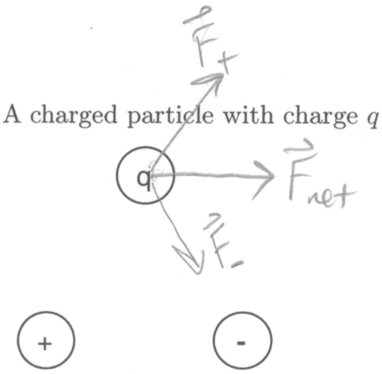
larger q results in larger force





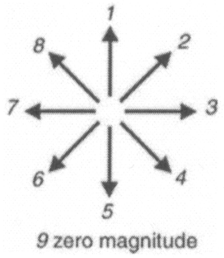
   [✓ (a)] 7
   (b) 3
   (c) The net force on Particle 2 is zero.

8. A charged particle with charge q is located equidistant from a proton and an electron as shown below.



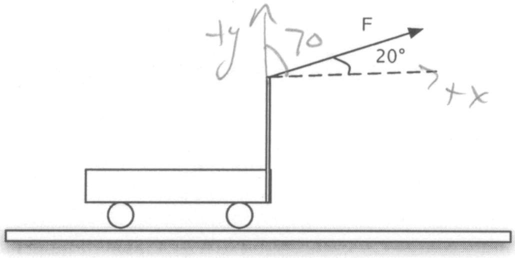
$\vec{F}_{net} = \vec{F}_+ + \vec{F}_-$

Which arrow below points in the direction of the net force on q if its charge is $+1e$, the charge of a proton.



(a) 9; because the net force on q is zero.
(b) 7
(c) 1
(d) 5
[✓ (e)] 3

Question 9–10: While helping freshmen move into the dorm, you pull a fully loaded cart of mass 100 kg at an angle of 20° with a force of magnitude 200 N to get it moving. The cart speeds up from 0 to 0.5 m/s in 2.0 s, while moving in the +x direction.



$F_{by\ me\ x} = 200\cos(20) = 188\ N$

$F_{by\ me\ y} = 200\cos(70) = 68\ N$

$F_{grav} = \langle 0, -980, 0 \rangle N$

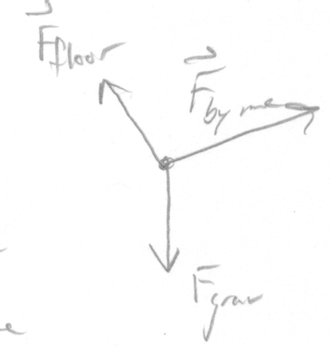
9. What is the net force on the cart during this time interval?

(a) zero
(b) $< 107, 0, 0 >$ N
(c) $< 980, 0, 0 >$ N
(d) $< 188, 0, 0 >$ N
[✓ (e)] $< 25, 0, 0 >$ N

$$\vec{F}_{net} = \frac{\Delta \vec{p}}{\Delta t} = \frac{m \Delta \vec{v}}{\Delta t}$$

$$= \frac{100\,kg\,(\langle 0.5, 0, 0 \rangle - 0)}{2\,s}$$

$$= \langle 25, 0, 0 \rangle N$$



10. What is the force by the floor on the cart during this time interval?
    - (a) < −188, 68, 0 > N
    - (b) < −25, 980, 0 > N
    - [✓ (c)] < −163, 912, 0 > N
    - (d) < −200, 980, 0 > N
    - (e) < 213, 1048, 0 > N

$\vec F_{net} = \vec F_{floor} + \vec F_{grav} + \vec F_{me}$

$\vec F_{floor} = \vec F_{net} - \vec F_{grav} - \vec F_{me}$

$= \langle 250,0\rangle - \langle 0,-980,0\rangle - \langle 188,68,0\rangle$

$= \langle -163, 912, 0\rangle$ N

11. A hammer is dropped from the roof of a building. Earth exerts a gravitational force of < 0, −8, 0 > N on the hammer. The gravitational force *on Earth* by the hammer is
    - (a) zero (or nearly zero)
    - (b) less than 8 N, upward
    - (c) greater than 8 N
    - [✓ (d)] 8 N, upward
    - (e) None of the above, because it depends on whether the hammer is falling or whether it has hit the ground and come to a stop.

$\uparrow \vec F_{on\ Earth\ by\ hammer}$

$\downarrow \vec F_{on\ hammer\ by\ Earth}$

Newton's third law

12. You drop a 2-kg object and a 1-kg object from the balcony of the lobby in Congdon Hall. On which object is the gravitational force by Earth the greatest?
    - (a) the 1-kg object
    - [✓ (b)] the 2-kg object
    - (c) Neither, because the gravitational force on each object by Earth is the same.

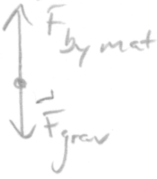
$|\vec F_{grav}| = mg$

13. For the two objects in the previous question, which object will hit the ground first?
    - (a) the 1-kg object
    - (b) the 2-kg object
    - [✓ (c)] Neither, because they will hit the ground at the same time.

$\vec F_{net} = \frac{\Delta \vec p}{\Delta t} = \frac{m\Delta \vec v}{\Delta t}$

m cancels in the momentum principle: $-\cancel{m}g = \cancel{m}\frac{\Delta v_y}{\Delta t}$

14. Suppose that a gymnast does a dismount and lands on a mat. During the time interval that she is in contact with the mat and is slowing down, the net force on her is < 0, 900, 0 > N. Her weight (the gravitational force by Earth on the gymnast) has a magnitude of 650 N. What is the force on the gymnast by the mat during the collision with the mat?
    - [✓ (a)] < 0, 1550, 0 > N
    - (b) < 0, −1550, 0 > N
    - (c) < 0, 250, 0 > N
    - (d) < 0, −250, 0 > N
    - (e) < 0, 650, 0 >



$\vec F_{net} = \vec F_{by\ mat} + \vec F_{grav}$

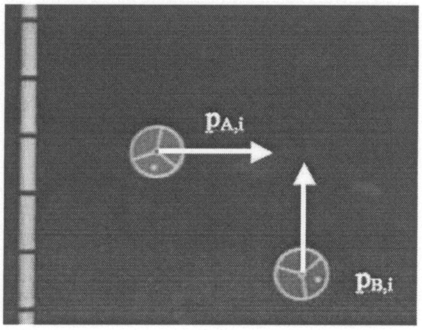
$\vec F_{by\ mat} = \vec F_{net} - \vec F_{grav}$

$= \langle 0,900,0\rangle - \langle 0,-650,0\rangle$

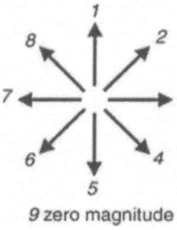
$= \langle 0,1550,0\rangle$ N

15. An astronaut in the space shuttle feels weightless. This is because
    - (a) Earth does not exert a significant gravitational force on her at this altitude.
    - (b) her speed is greater than the escape speed.
    - (c) there is no air resistance.
    - [✓ (d)] she is in free-fall around Earth.
    - (e) she is not in an elliptical orbit.

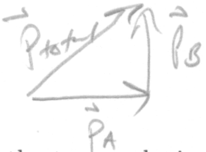
16. Questions 16–18: Two pucks have the initial momenta shown below before they collide.



If you define the *system* to be the two pucks, which arrow below points in the direction of the total momentum of the system?



$\vec{P}_{total} = \vec{P}_A + \vec{P}_B$



- (a) 9; because the total momentum of the two pucks is zero.
- (b) 4
- (c) 1
- (d) 3
- [✓ (e)] 2

17. After the collision occurs,

- [✓ (a)] the total momentum will be the same as before the collision.
- (b) the total momentum of the system will be zero.
- (c) the total momentum will be less in magnitude, but in the same direction as the total momentum before the collision.
- (d) the total momentum will be equal in magnitude, but opposite in direction to the total momentum of the system before the collision.

$\vec{F}_{net} = 0$ so

$\vec{P}_{system}$ is constant

Conservation of momentum!

18. What is required for the total momentum of a system to be constant (i.e. conserved),

- (a) The system must be made up of exactly two objects.
- (b) The objects in the system must collide.
- (c) The objects in the system must be connected.
- (d) The total momentum of the system must equal zero.
- [✓ (e)] The net external force on the system must equal zero.

$\vec{F}_{net} = \frac{\Delta \vec{p}}{\Delta t}$

If $\vec{F}_{net} = 0$, then $\Delta \vec{p} = 0$ and

$\vec{p}_f = \vec{p}_i$

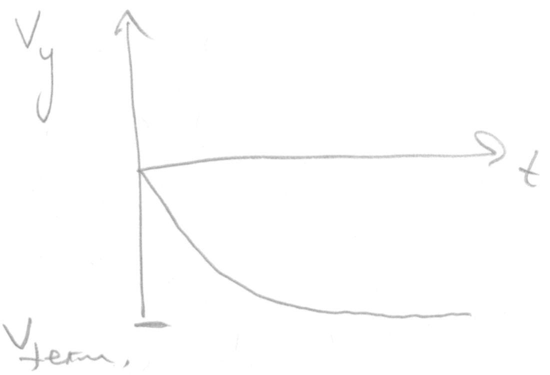
Questions 19–20: A BASE jumper falls from rest from the top of a cliff. As she falls, her speed increases until he reaches terminal speed.

19. As she is falling, before she reaches terminal speed, the magnitude of the force by air resistance on the BASE jumper

    [✓ (a)] increases until it is equal to the magnitude of the gravitational force on the BASE jumper.
    (b) decreases until it is zero.
    (c) is constant and non-zero.
    (d) is constant and equal to zero.

20. As she is falling, before she reaches terminal speed, the magnitude of the net force on the BASE jumper

    (a) increases until it is equal to the magnitude of the gravitational force on the BASE jumper.
    [✓ (b)] decreases until it is zero.
    (c) is constant and non-zero.
    (d) is constant and equal to zero.

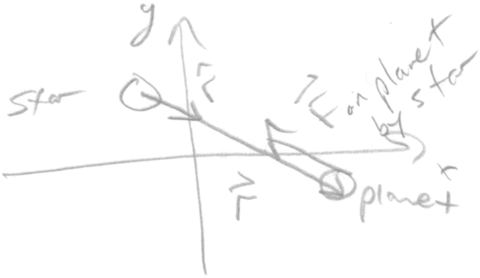


$|\vec{F}_{air}| = Dv^2$ so it increases as her speed increases.

at $v = v_{term}$ $\vec{v}$ is constant, $\vec{F}_{net} = 0$.

Section 2. Problem Solving

21. (a) A planet of mass 4e24 kg is at location $< 5e11, -2e11, 0 >$ m. A star of mass 5e30 kg is at location $< -2e11, 3e11, 0 >$ m. Sketch a coordinate system, and show the planet, the star, and vectors for the position of the planet relative to the star, the unit vector $\hat{r}$, and the gravitational force on the planet by the star.



(b) What is the gravitational force on the planet by the star?

$$|\vec{F}_{grav}| = G\frac{m_1 m_2}{|\vec{r}|^2} \qquad \vec{F}_{grav} = |\vec{F}_{grav}|(-\hat{r})$$

$$\vec{r} = \vec{r}_{planet} - \vec{r}_{star}$$

$$= \langle 5\times10^{11}, -2\times10^{11}, 0\rangle m - \langle -2\times10^{11}, 3\times10^{11}, 0\rangle m$$

$$= \langle 7\times10^{11}, -5\times10^{11}, 0\rangle m$$

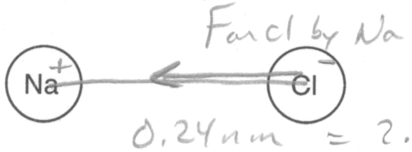
$$|\vec{r}| = \sqrt{7^2+5^2}\times10^{11} = 8.6\times10^{11} m$$

$$\hat{r} = \frac{\vec{r}}{|\vec{r}|} = \frac{\langle 7\times10^{11}, -5\times10^{11}, 0\rangle}{8.6\times10^{11}} = \langle 0.814, -0.581, 0\rangle$$

$$|\vec{F}_{grav}| = \frac{(6.7\times10^{-11} N\frac{m^2}{kg^2})(5\times10^{30} kg)(4\times10^{24} kg)}{(8.6\times10^{11} m)^2} = 1.81\times10^{21} N$$

$$\boxed{\vec{F}_{grav} = \langle -1.47\times10^{21}, 1.05\times10^{21}, 0\rangle N}$$

22. A model of a NaCl molecule is shown below. The sodium ion is positively charged with a charge $+1e$, or -1.6×10^{-19} C.The chloride ion is negatively charged with a charge $+1e$ or $+1.6 \times 10^{-19}$ C. The bond length of sodium chloride is about 0.24 nm which is 2.4×10^{-10} m. Using this as the distance between the atoms, calculate the Coulomb force on the Chloride ion by the sodium ion. Express your answer as a vector. Sketch the direction of this force and verify that your answer agrees with the sketch.



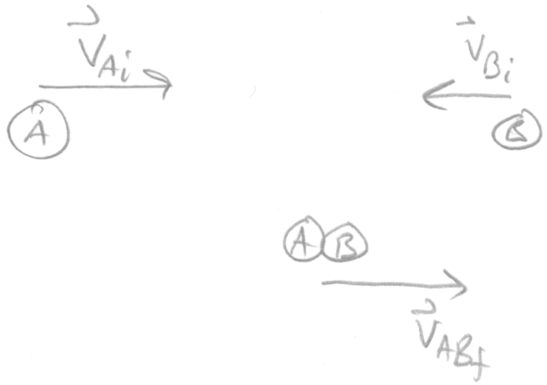
0.24 nm $= 2.4 \times 10^{-10}$ m

$$|\vec{F}|_{coul} = \frac{(9\times10^{9})|q_1 q_2|}{|\vec{r}|^2} = \frac{\left(9\times10^{9}\,\frac{N m^2}{C^2}\right)\left(1.6\times10^{-19}C\right)\left(1.6\times10^{-19}C\right)}{\left(2.4\times10^{-10}m\right)^2}$$

$$= 4 \times 10^{-9}\ N$$

$$\boxed{\vec{F}_{coul} = \langle -4\times10^{-9}, 0, 0 \rangle\ N}$$

23. A hockey puck (A) on an air hockey table has mass $m_A = 0.100$ kg and initial velocity $v_{A,i} =< 2, 0, 0 >$ m/s just before it collides with another hockey puck (B), which has mass $m_B = 0.050$ kg. Just before the collision, puck B has a velocity $v_{B,i} =< -1, 0, 0 >$ m/s. The pucks stick together (because they are wrapped in velcro) upon colliding. What will be the velocity of the system after the collision? Sketch a picture showing the pucks and the total momentum before the collision and the pucks and the total momentum after the collision and use your picture to verify the correctness of your answer.



$m_A = 0.1$ kg

$m_B = 0.05$ kg

$\vec{V}_{Af} = \vec{V}_{Bf}$

$\vec{V}_{Ai} = \langle 2, 0, 0 \rangle \frac{m}{s}$

$V_{Bi} = \langle -1, 0, 0 \rangle \frac{m}{s}$

Since the table is frictionless, $\vec{F}_{net} = 0$ during the collision for the system of pucks. Define system as the two pucks together.

$$\vec{P}_{sys\,i} = \vec{P}_{sys\,f}$$

$$\vec{P}_{Ai} + \vec{P}_{Bi} = \vec{P}_{Af} + \vec{P}_{Bf}$$

$$m_A \vec{V}_{Ai} + m_B \vec{V}_{Bi} = m_A \vec{V}_{Af} + m_B \vec{V}_{Bf} = (m_A + m_B) \vec{V}_f$$

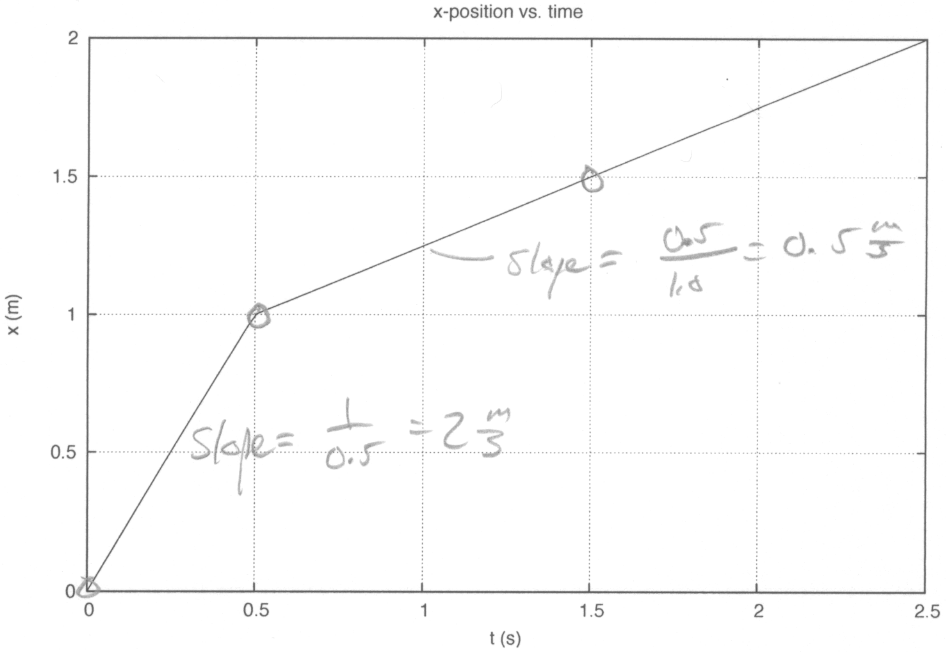
$$(0.1)(\langle 2,0,0 \rangle) + (0.05)(\langle -1,0,0 \rangle) = (0.05 + 0.1) \vec{V}_f$$

$$\langle 0.2, 0, 0 \rangle + \langle -0.05, 0, 0 \rangle = (0.15) \vec{v}_f$$

$$\langle 0.15, 0, 0 \rangle = 0.15 \vec{v}_f$$

$$\boxed{\vec{V}_f = \langle 1, 0, 0 \rangle \frac{m}{s}}$$

24. (a) Two carts make a head-on collision on a track. You use video analysis to measure the position as a function of time for one of the carts. Curve fits for the data are shown below. If the mass of the cart is 0.5 kg, what is Δp_x for the cart due to the collision?



slope $= \frac{0.5}{1.0} = 0.5 \frac{m}{s}$

Slope $= \frac{1}{0.5} = 2 \frac{m}{s}$

V_x is the slope of x vs. t

$V_{xi} = 2 \frac{m}{s}$

$V_{xf} = 0.5 \frac{m}{s}$

$\Delta p_x = m \Delta V_x = m(V_{fx} - V_{ix})$

$= (0.5 kg)(0.5 - 2) = (0.5)(-1.5)$

$\boxed{\Delta p_x = -0.75 kg \frac{m}{s}}$

(b) In what direction was the force on the cart due to the collision? (i.e. Was it in the +x direction or in the [✓ −x direction?]) Explain your answer.

$\vec{F}_{net} = \frac{\Delta \vec{p}}{\Delta t}$ Since Δp_x is $-$, F_{net_x} is $-$.

25. Suppose that two BASE jumpers have the same mass. Jumper A has a greater drag constant than [✓ Jumper B.] Which jumper will have a greater terminal speed?

Jumper B

$\vec{F}_{air}$

$\vec{F}_{grav}$

at term speed. $|\vec{F}_{air}| = |\vec{F}_{grav}|$

$D v_{term}^2 = mg$

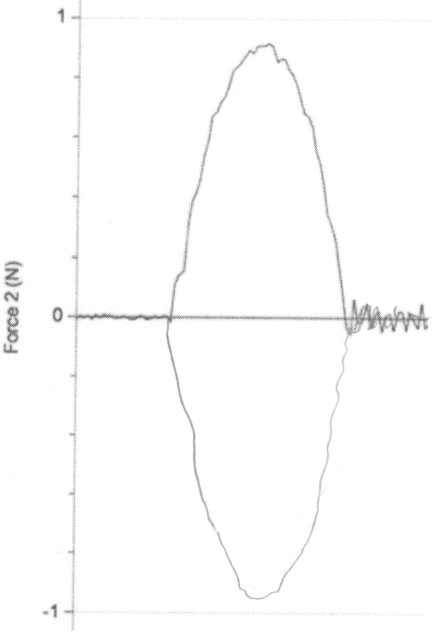
$V_{term} = \sqrt{\frac{mg}{D}}$ so greater D, less V_{term}

26. Suppose that two BASE jumpers have the same drag constant. Jumper A has a greater mass than Jumper B. Which jumper will have a greater terminal speed?

$V_{term} = \sqrt{\frac{mg}{D}}$ greater m, greater V_{term}

Jumper A

27. Cart A makes a head-on collision with Cart B. A graph of F_x vs. t for Cart A during the collision is shown below. Sketch a curve for F_x vs. t for Cart B on the same set of axes below.



$F_{A\,on\,B\,x} = -F_{B\,on\,A\,x}$

28. What physical quantity does the area under the curve of F_x vs. t during the time interval of the collision give us? (Note: just say the physical quantity that the area represents; you don't need to calculate the area. Oh, and I know it's the integral, so don't just say that it's the integral of $F_x dt$. I want to know what it *represents*.)

$\Delta p_x = \int F_x dt$ so it is $\boxed{\Delta p_x}$

29. What is the approximate diameter of a nucleus?

10^{-15} m

30. What is the approximate diameter of an atom (which includes the electron "cloud" around the nucleus)?

10^{-10} m

31. Venus has an orbital period of 224.7 days (i.e. Earth days, 24 hours/day). It has a nearly circular orbit with approximate radius 1.08×10^{11} m. What is the speed of Venus in m/s? (Hint: it moves around a circle in 224.7 days.)

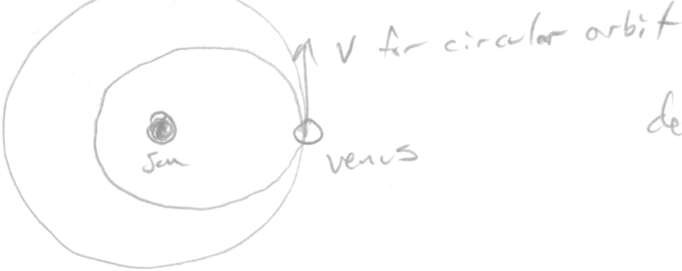
distance $= 2\pi R = 2\pi(1.08 \times 10^{11}\,m) = 6.79 \times 10^{11}\,m$

$\Delta t = (224.7\,days)\left(\frac{24\,h}{day}\right)\left(\frac{60\,min}{h}\right)\left(\frac{60\,sec}{min}\right)$

$= 1.94 \times 10^{7}\,s$

$V = \frac{6.79 \times 10^{11}\,m}{1.94 \times 10^{7}\,s} = \boxed{3.5 \times 10^{4}\,\frac{m}{s}}$

32. Suppose that in a VPython simulation of Venus orbiting Sun, you start with an initial velocity that gives a circular orbit. If you decrease this initial velocity by a factor of 0.9, for example, what will be the resulting path of the orbit? (a circle, ellipse, parabola, or hyperbola?)



decreasing $|\vec{v}|$ results in an ellipse.